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***Abstract*— Despite years of development and deployment, the standardized IEEE802.11p communication for vehicular networks can be pushed toward insatiable performance demands for wireless network data access, with a remarkable increase of both latency and channel congestion levels when subjected to scenarios with a very high vehicle density. In some hard safety applications such as convoys, IEEE802.11p could seriously fail to meet the fundamental vehicular safety requirements. On the other hand, the advent of LED technologies has opened up the possibility of leveraging the more robust Visible Light Communication (VLC) technology to assist IEEE802.11p and provide seamless connectivity in dense vehicular scenarios. In this paper, we propose and validate a prediction-based vertical handover (PVHO) between VLC and IEEE802.11p meant to afford seamless switching and ensure the autonomous driving safety requirements. Algorithm validation and platoon system performance were evaluated using a specially implemented 802.11p-VLC module in the NS3 Network Simulator. The simulation results showed a speed-based dynamic redundancy before and after VLC interruptions with seamless switching. Moreover, the deployment of VLC for platoon intra-communication can achieve a 10-25% PDR gain in high-density vehicular scenarios.**

Keywords: VLC, IEEE802.11p, Platoon, NS3, ITS, Road safety applications.

I. Introduction

The remarkable advances in Light-Emitting-Diode (LED) technologies, together with the saturation of the Radio Frequency (RF) spectrum [1–3] has leveraged optical-based communication solutions to become a reliable assisting technology to support conventional RF solutions due to its broad bandwidths, high-security characteristics, independence of any electromagnetic interference, energy efficiency, and dual functionality nature [4].

There has been a recent tendency to study hybrid solutions combining both Visible light Communication (VLC) and RF networks, which are expected to take advantage of the characteristics of both technologies [5–7]. Nonetheless, VLC like all optical-based technologies, is line-of-sight (LoS) dependent and outdoor environment sensitive. Therefore, the heterogeneous VLC-RF network is often introduced for indoor applications, where both ambient noise and mobility effects are relatively low. The primary motivation behind such heterogeneous structures is achieving higher data rates and better perceptible Quality of Experience (QoE).

In addition to the presence of severe ambient noise, further challenges can arise when deploying VLC for Intelligent Transport Systems (ITS), where there is no guarantee of Line of Sight (LoS) continuity, especially for sharp curvature scenarios, due to the highly mobile nature of the vehicular environment. Therefore, signal obstructions are expected to occur often, making the Field-of-View (FOV) of both the transmitter and receiver units design as one of the most significant limitations for the deployment of VLC in the vehicular environment.

Some of the optimal up-to-date deployment scenarios of VLC within ITS have been the following:

1) Infrastructure-to-Vehicle (I2V): The traffic lights serving as a broadcasting down-link access-point [8].
2) Vehicle-to-Vehicle (V2V): Inter-Vehicle Communication (IVC) for convoy-based applications such as platooning. [9], [10]

As depicted in Fig 1, the inter-vehicle distances are relatively short, and LoS can be maintained along the driving scenarios with some potential disconnections occurring during any sharp curvature or maneuvers [11]. Therefore, VLC will not be able to operate independently from any RF communication solutions to provide continuous data access. However, VLC can be highly effective as a complementary solution to assist IEEE802.11p when utilizing a proper handover mechanism accommodating the vehicular environment, especially for high density and mobility scenarios.

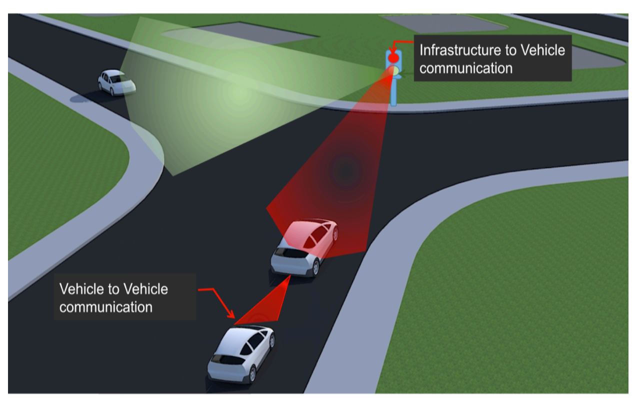

Fig. 1. The two main deployments scenarios for VLC technology in ITS. First is the I2V broadcast from traffic lights to vehicles, the second is V2V communication in the form of IVC between adjacent vehicles.

Hence, this paper proposes the use of a prediction-based handover mechanism deploying the VLC and IEEE802.11(RF) technologies in a complementary manner to ensure data transmission continuity and minimize the dependency on RF communication channel, while meeting the safety requirements for ITS convoy-based applications.

The remainder of this paper is organized as follows: Section II presents related work and a review of the literature. The RF-VLC over-all system architecture is presented in Section III. RF-VLC modeling in a network simulator is detailed in Section V. The PVHO handover mechanism is presented in detail in Section VI. We report on the system's performance and simulation configuration in Section VII. Finally, the conclusion and future work are given in Section VIII.

II. Related Work & existing conventional VHO schemes

There have been several studies investigating how VLC and RF systems can operate in a complementary mode. The authors of [12] have studied the required criteria of VHO for VLC-WiFi systems, suggesting a service disconnection avoidance technique. An interesting study was presented by the authors of [13], where they studied handover schemes for two independent mobile VLC situations: non-overlapping (spotlighting) cases and overlapping (uniform lighting) cases. However, the work focused mainly on a horizontal handover rather than a vertical one. In [14], an implementation of a hybrid communication system was presented to monitor a VLC link predefined metrics and quickly switch to RF whenever VLC is interrupted. Such a technique cannot be suitable for ITS safety-related applications due to the excessive latency in detecting failure added to the switching time involved.

Chowdhury and Katz in [7] have investigated the performance of VLC-WLAN hotspot networks in a mobile scenario, but the impact of VHO schemes was neglected assuming a seamless handover. An advanced fuzzy logic-based VHO decision-making algorithm was proposed to solve the issue of short and long LoS blocking for a coordinated radio and infrared system in [6]. This approach is limited by its dependency on preliminary datasets extracted by learning and training.

Between any heterogeneous wireless networks, there are differences in properties and mechanisms at both the physical and data-link layers, which raises a significant challenge for mobility management in an integrated system, especially when considering a combination of optical and radio-based communication solutions.

When a vehicle crosses the coverage boundary of two different communication systems, its crucial to maintain the connection continuity throughout the driving scenario, and any switching must be seamless with relatively low latency and a guaranteed QoS.

Such a cross-system transfer of an ongoing connection is usually referred to as an inter-system or vertical handover (VHO) [15], where the term VHO often represents the VHO architecture and the VHO decision-making algorithm. As the VHO architecture is the approach and system configuration applied to the connection reconstruction in a handover process, this paper focuses on the design and evaluation of a prediction-based VHO decision-making algorithm for the proposed integrated IEEE80.11p(RF)-and-VLC system for vehicular convoy-based applications.

In general, two main conventional decision-making handover schemes are used for basic VHO algorithms in implementations of heterogeneous VLC-RF systems:

1) The Immediate VHO (IVHO), which performs an immediate handover after detecting interruption (hard-handover).
2) The dwell VHO (D-VHO), which waits for a fixed period of time (in case communication is recovered) before performing a VHO.

Figure 2 represents the flow diagrams of these two basic mechanisms. The IVHO algorithm is designed to merely monitor the availability of VLC connectivity and data flow. If available, the algorithm will switch the reception to the VLC channel immediately. Whenever an interruption occurs, the IVHO mechanism performs an instant switching back to the RF channel and avoids any waiting, as depicted in Fig 3.(a) with a potential introduction to a redundant period (τ_r).

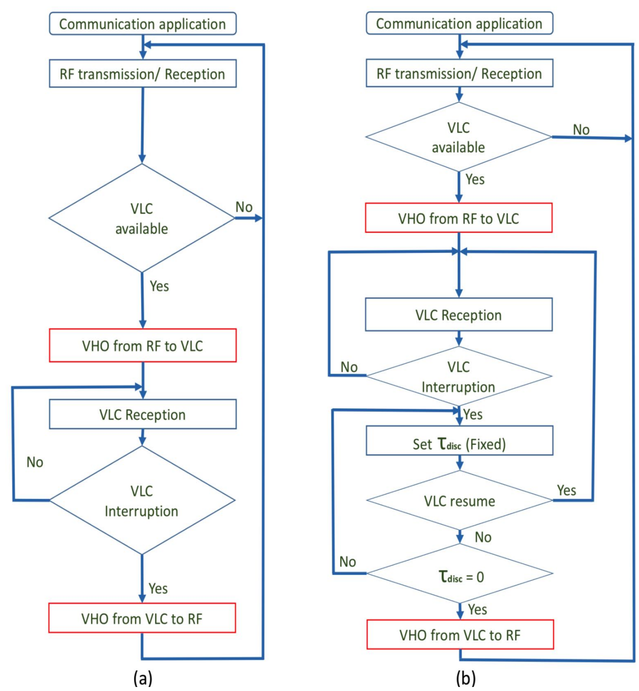

Fig. 2. Flow diagram of the two conventional handover mechanisms, (a) the immediate VHO, (b) the dwell VHO.

On the other hand, and as depicted in Fig 3.b, the more advanced D-VHO mechanism uses a predefined fixed time τ_{disc}, where a monitoring timer was mainly introduced to prevent any decision fluctuation. The delayed activation of the RF transmission will allow the VLC to recover the transmission if the interruption is shorter than a predefined dwell time τ_{disc}, which represents the time in which the system can hold (waiting for the VLC to recover before switching to the RF). Once τ_{disc} timer expires, the handover to RF will be applied immediately, after some additional execution time.

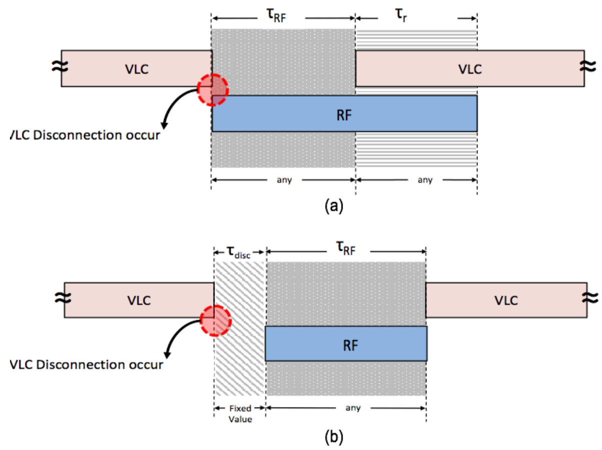

Fig. 3. Conventional Handover mechanisms between VLC and RF (a). IVHO switching mechanism (b).D-VHO switching mechanism.

The authors of [14] compared the performance of both D-VHO and I-VHO schemes and observed that the IVHO could expedite the switching only when there is a long interruption occurrence or when the size of unsent messages is small enough to get a faster delivery after switching to the radio link. Moreover, when there is a frequent or short interruption occurrence, or when the size of the unsent messages is relatively large, the I-VHO method showed a poor latency performance compared to D-VHO.

It can also be concluded from the results of [14] that compared to the uni-system, the assisting technologies can improve the communication quality and decrease the average transfer delay if proper VHO is performed. However, under different network and traffic conditions, such as vehicular networks unique requirements, different handover strategies need to be deployed, and different metrics need to be considered to ensure communication continuity. Consequently, neither of the two primary schemes are expected to offer an acceptable level of performance for the vehicular environment, especially given the fact that optical link interruptions are expected to occur frequently and to be of random duration due to the mobility and different road curvatures.

To our best knowledge, most of the proposed handover algorithms are not expected to meet either ITS safety requirements or vehicular environmental conditions. Hence, some modification to the conventional VHO mechanism is required to ensure a proper switching solution that takes into the account the specific nature of the vehicular environment. In this context, we propose a PVHO mechanism to predict any VLC interruption before the actual occurrence and extend a comfortable communication redundancy to ensure a seamless handover.

III. RF-VLC SYSTEM ARCHITECTURE

As we demonstrated in our earlier work, the greater the deployment of VLC among platoon members and the more protracted the platoon formulations are, the lower is the RF channel load and the better is the overall communication performance [16]. Therefore, when designing a handover RF-VLC system, the primary intention is to enable VLC between platoon members as much possible and ensure seamless switching without experiencing any disconnection in the autonomous-based platoon.

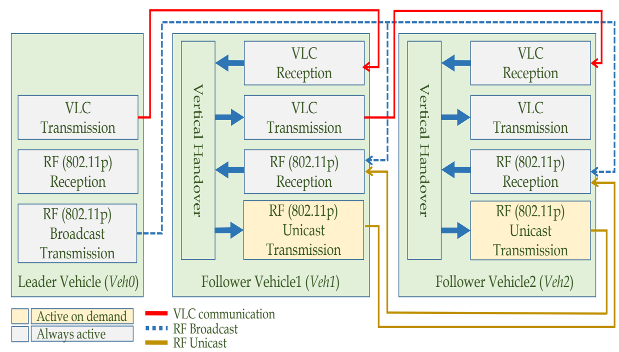

Fig. 4. RF-VLC communication system architecture for the platooning application.

Figure 4 illustrates the communication configurations of the proposed RF-VLC system for the platooning application where we intend to evaluate the PVHO mechanism. The highlighted stages in $followervehicles1$ and 2 (RF unicast transmission/reception) are the only on-demand activated stages, whereas all the other stages are active throughout the entire application activation period. Since VLC provides a half-duplex communication link, the RF unicast transmission stages are used to inform the preceding vehicle when the follower vehicle predicts any upcoming VLC interruptions. A trigger message will be received by the (RF (802.11p) unicast reception) to activate the preceding vehicle (RF (802.11p) unicast transmission) and consequently switch to the RF channel upon request.

All platoon members using the RF-VLC system are assumed to have a highly accurate positioning capability (GPS systems) for an accurate relative vehicular orientation calculation, as will be further detailed in Section V.

IV. RF-VLC SWITCHING KEY METRICS FOR PLATOONING

Any VLC link interruption occurrence will directly affect the packets that have been partially transmitted or are waiting for transmission. The Packet inter-reception Time (PiT) which is defined as the time required to successfully receive two subsequent packets while considering each packet sequence order, has a direct impact on the continuity of the communication process and safety requirements. Furthermore, tracking the reception of subsequent VLC packets meant to sense the situations when the FOV requirements might be satisfied with the presence of a blocking obstacle.

We suggest the following metrics as the performance indicators of our vertical handover strategy:

1) Packet sequence (N): The handover algorithm can track the sequence of the VLC received packets, any certain jump in the sequence number such as $\Delta N \geq 4$ will trigger the handover to the RF channel.
2) Message length (l): Our system transmits packets of a fixed length, where any change in the received packet length can be counted as a partially received packet. Consequently, a VLC link interruption occurrence will be assumed.
3) Vehicles relative orientation: This metric is the key metric for the PVHO mechanism and represents the relative angular orientation between two subsequent platoon members. The misalignment tracking is vital to predicting upcoming VLC link interruptions.

The difference between two subsequent packet numbers ΔN was chosen based on the experimental results of the VLC prototype validation in [10]. The validation for vehicular scenarios showed that the average PiT system was no more than $33ms$ when the VLC delivered its best performance. Therefore, the system can handle three subsequent missed packets of a total update time = 3×33=99 ms. If three subsequent packets are lost ($\Delta N \geq 4$), the system reception delay time will exceed the application $100ms$ safety limits; consequently, ΔN was set to be ≤ 3. Further details regarding the vehicular relative-orientation metric and tracking mechanism are given in NS3 Model implementation.

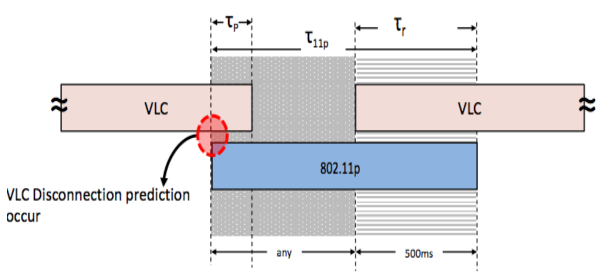

Fig. 5. Prediction-based VHO switching stages between VLC and the IEEE802.11p.

In order to achieve communication continuity of the RF-VLC system, we propose an extended version of the D-VHO mechanism as depicted in Fig 5. The proposed PVHO mechanism implies using a realistic fixed redundancy time period $\tau_r = 500ms$, which is a long enough period to successfully receive about 10 packets over the VLC channel before disabling the RF transmission and is meant to prevent any fluctuation of the switching mechanism. Since PVHO is designed to detect any potential VLC interruption, a dynamic redundancy period (τ_p) is proposed to enable both technologies based on the prediction angle (θ_p), as will be detailed in the following section.

V. VLC Model in NS3 and vehicular orientation calculations

The VLC model for the proposed PVHO mechanism validation is mainly developed using the open source code on how an NS3 module can be used to study hybrid WiFi/VLC systems for an indoor environment [17].

The initial implementation by the authors provided a basic VLC channel model using the existing NS3 P2P channel module, where the implementation considered exclusive signal corrupting factors for indoor communication and short distance scenarios [18]. The calculations and parameters of the Signal-to-Noise-Ratio (SNR), transmitter power, receiver aperture, the filtering stage, and propagation loss models were further improved to adapt to outdoor vehicular conditions and platoon mobility.

Our contribution to the model was mainly the calculation of the orientation of the NS3 nodes and replacing the wifi module with the standardized WAVE(IEEE802.11p). The PVHO algorithm was also implemented in the VLC-NS3 module MAC layer to calculate the algorithm metrics and enable seamless switching between technologies as depicted in Fig 6. We also applied real-world SUMO mobility tracings for scenarios implementations recognizing different road curvatures, speed, platoon formation, and different vehicle densities.

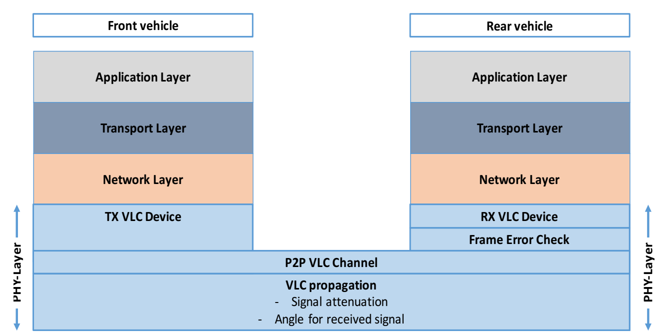

Fig. 6. NS3-VLC Module for PVHO algorithm and vehicular orientations calculations.

The PVHO suggests using related vehicle speed, maximum vehicle speed, and the angular orientation between every two platoon members to predict the VLC interruption. As will be further detailed, the prediction decision is based on processing the prediction angle (θ_p) in each node after acquiring the preceding vehicle's orientation. The process tracks the FOV between any two vehicles in platoon formation and dynamically forces a redundant period between RF and VLC (τ_p) before disconnection occurs due to any calculated misalignment (sharp curvatures).

To find θ_p, the proposed RF-VLC system assumes that each platoon member is equipped with an accurate positioning system providing the $(\acute{x}, \acute{y})$ and (x, y) coordination, which represents the coordination of *Preceding vehicle* and *Follower vehicle* respectively.

As depicted in Fig 7, an initial mobility displacement is considered in the NS3 PHY layer implementation to calculate the vectors $\vec{F}$ and $\vec{R}$ which represent the relative orientation of each node (vehicle). The inter-vehicle distance is represented by the vector $\vec{P}$, where each of these vectors values is updated and calculated in the NS3 PHY-Layer for every mobility updates.

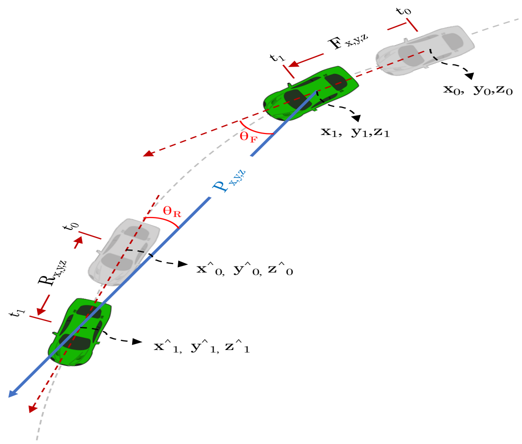

Fig. 7. Calculating vehicular relative orientation in NS3.

By performing a dot product between the vectors obtained in (1), we can calculate both θ_R and θ_F in (2), which represent the incidence and irradiance angles of the VLC link. The same angles can also be named the front and real relative angles between any two platoon members.

$$\begin{bmatrix} \vec{F}_{(x,y,z)} \\ \vec{R}_{(x,y,z)} \\ \vec{P}_{(x,y,z)} \end{bmatrix} = \begin{bmatrix} (x_1 - x_0), (y_1 - y_0), (z_1 - z_0) \\ (\hat{x}_1 - \hat{x}_0), (\hat{y}_1 - \hat{y}_0), (\hat{z}_1 - \hat{z}_0) \\ (\hat{x}_1 - x_1), (\hat{y}_1 - y_1), (\hat{z}_1 - z_1) \end{bmatrix} \tag{1}$$

$$\begin{cases} \theta_R = \arccos(\frac{\vec{R}.\vec{P}}{|R||P|}) \\ \theta_F = \arccos(\frac{\vec{F}.\vec{P}}{|F||P|}) \end{cases} \tag{2}$$

After developing explicit relations between the vehicles' orientation and both front and rear angles, we can use this information to track the relative misalignment between both vehicles in real time. By now, the VLC between autonomous platoon members will certainly experience disconnection when($max(\theta_R, \theta_F) \geq \theta_c$), where θ_c represents the critical optical FOV limitation.

To dynamically enable RF and VLC redundancy before the actual VLC disconnection occurs (see Fig 5). The mechanism suggests using the average platoon speed v and the maximum vehicle speed v_{max} to regulate the dimension of this redundancy period as follows:

$$\theta_p = \theta_c \left(1 - \frac{1}{2} \frac{v^2}{v_{max}^2}\right). \tag{3}$$

Since the platoon formation is often a constant inter-vehicle distance approach, we chose to use the relative platoon speed to update the prediction angle. The term $\frac{1}{2}\frac{v^2}{v_{max}^2}$ has been selected to decrease the prediction angle threshold following square law shape while the speed increases. Figure 8 shows the dynamic relation between relative vehicle velocity and the prediction angle for an optical critical angle $\theta_c = 15°$.

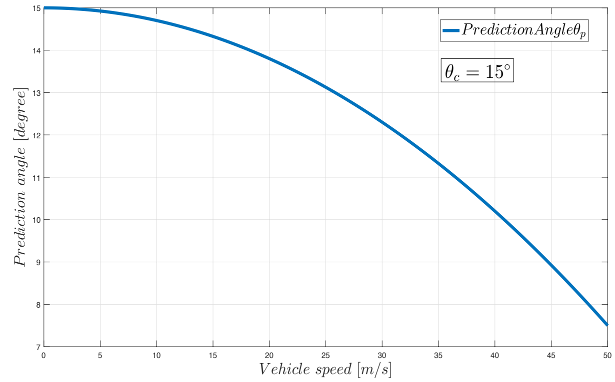

Fig. 8. The relation between prediction angle θ_p and average vehicle speed.

VI. The Prediction VHO algorithm

To this end, we can see that the core of the proposed PVHO algorithm is to continuously check if the $max(\theta_R, \theta_F) < \theta_p$, where the value of θ_p is platoon speed dependent. Once the condition is no longer satisfied, the algorithm decides that a VLC disconnection is about to occur. Therefore, instant activation of the RF is executed to provide seamless switching and ensure communication continuity.

Since both ΔN and l errors checks are due to the rare presence of obstacles between platoon members, any further VLC interruption detection due to the metric ΔN, or l, will turn the algorithm to an immediate handover switching. Otherwise, if the disconnection is expected to occur due to FOV misalignment, the system will have a soft-handover, where the RF stages are activated before the VLC disconnection occurs as will be discussed in the next section.

The detailed Algorithm 1 operates in a decentralizing way, where each platoon member executes the same algorithm making a local independent decision. The PVHO mechanism has the initializations status activating both RF and VLC communication. The $(find(\theta_p, \Delta N, l))$ function is called at lines 5,11,26 to check any misalignment between any two platoon members and confirm the availability of VLC.

If VLC is available, at line 9, the algorithm sets a timer $\tau_r = 500ms$ to avoid any switching fluctuation before performing the handover. The same forced redundancy period is applied at line 23 to avoid any decision fluctuation, where the RF activation due to any VLC interruption takes an immediate action as in line 20.

VII. Simulation scenarios and evaluation

Different simulation scenarios were prepared using both NS3 network simulator and the SUMO mobility simulator to validate the performance before and after deploying the VLC as an assisting technology alongside the IEEE802.11p. Two major scenarios depicted in Fig 9 were built in NS3 to estimate the IEEE802.11p channel congestion improvement when VLC is enabled between platoon members.

- **Scenario I RF**
  Path length is 10 km. There are three lanes of random traffic and one lane dedicated to multi-platoon formation

Algorithm 1: The Prediction VHO algorithm

Platoon system initialization;
Activate RF transmission/reception;
Activate VLC transmission/reception;
while *Active* **do**
  find($\theta_p, \Delta N, l$) ▷ compute θ_p, ΔN, l
  if $(max(\theta_R, \theta_F) \leq \theta_p \;||\; \Delta N_{packet} \leq 3)$ **then**
    $\tau_{init1} \leftarrow system\_time$
    $\tau_r \leftarrow 0ms$
    while $(\tau_r < 500ms)$ ▷ *fluctuation avoidance*
    do
      find($\theta_p, \Delta N, l$) ▷ compute θ_p, ΔN, l
      if $(max(\theta_R, \theta_F) > \theta_p \;||\; \Delta N > 3)$ **then**
        $\tau_r \leftarrow 0ms$ ▷ reset $\tau_{Redundant}$
      else
        $\tau_r \leftarrow (system\_time - \tau_{init1})$;
      end
    end
    Deactivate RF ▷ RF to VLC VHO $\Longrightarrow$
  else
    Immediate Activate RF ▷ VLC to RF VHO $\Longleftarrow$
    $\tau_{disc} \leftarrow 0ms$;
    $\tau_{init} \leftarrow system\ time$;
    while $(\tau_{disc} \leq 500ms)$ ▷ *fluctuation avoidance*
    do
      $\tau_{init2} \leftarrow system\ time$;
      find($\theta_p, \Delta N, l$) ▷ compute θ_p and $\Delta N, l$
      if $(max(\theta_R, \theta_F) \leq \theta_p \;||\; \Delta N \leq 3)$ **then**
        $\tau_{disc} \leftarrow (system\_time - \tau_{init2})$;
      else
        $\tau_{disc} \leftarrow 0$;
      end
    end
  end
end

and varying curvatures. All the vehicles in this scenario use radio communication to broadcast information.

- **Scenario II VLC-RF**
  The same configuration as **Scenario I** with the difference that the following vehicles in the platoons are using the VLC in assisting mode by deploying the PVHO mechanism.

The overall system performance was evaluated by extracting the PDR, redundancy periods before VLC disconnection occurring for different road trajectories. Fig 10 represents a sample of the sharp curvature along the simulation scenario where the VLC link was pushed beyond the FOV threshold to test the performance of the PVHO mechanism.

The simulation scenarios using SUMO mobility were set to resemble the spare, medium, and high-dense traffic conditions of the 4 lanes presented in Fig 9, where the communication and mobility configurations are detailed in Table I.

Figure 11 draws a comparison between the results obtained

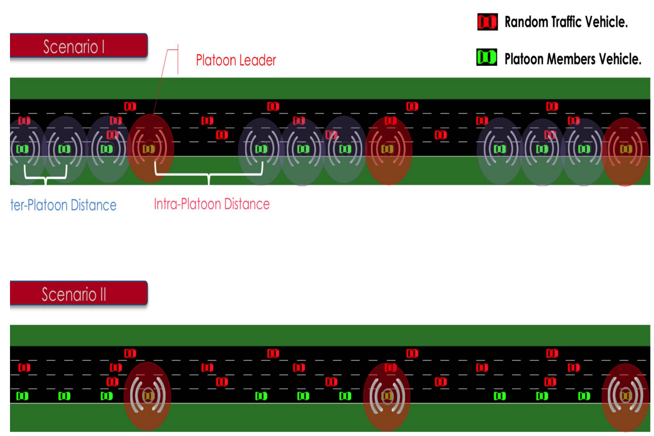

Fig. 9. Four-lane simulation scenarios in NS3: Scenario I enables RF communication broadcast for all vehicles. Scenario II enables RF broadcast for all vehicles except platoon followers, where VLC is enabled as IVC between platoon members with an active PVHO mechanism.

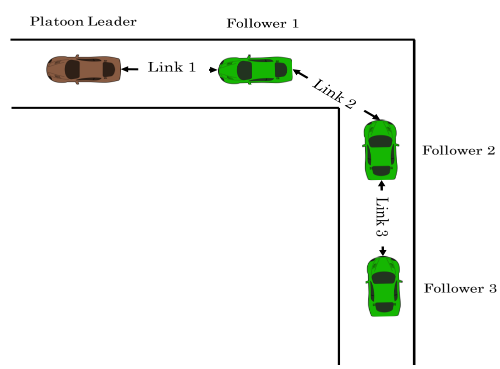

Fig. 10. Sample of a sharp road curvature in SUMO mobility for the platoon dedicated-lane (90° turning scenario).

TABLE I

MOBILITY AND COMMUNICATION PARAMETERS FOR MULTI-LANE VEHICULAR DISTRIBUTION

Communication simulator	NS3-23 WAVE Module - 2015
Number of nodes	600 (vehicle/node)
	V2V communication - No RSUs
Application	Vehicular safety messaging - VANET
	Broadcast-message based
	100ms update time - CAM
	Communication range - Omnidirectional 500m
	Sensing range 1km
Mobility simulator	SUMO 0.26 - 2015
Lane length	10 km
Lanes numbers	4 lanes - bi-directional
Maximum lane speed	25 m/s
Maximum turning speed (forced)	15 m/s
	One lane dedicated for platoon
	Lane number 1
Inter-vehicle distance	8 m
Intra-platoon distance	24 m
Number of platoons	22 formation
platoon size	4 vehicles
Number of platoon members	22x4=88 vehicle
Number of non-platoon members	600-88= 512 vehicle
Random vehicle speed	Mixed speed Min 10 m/s - Max 20 m/s
Platoon speed	Constant speed 12 m/s

from the standard situation when all the vehicles are using the IEEE802.11p communication (All Platoon Members BroadCast) and the performance when the PVHO mechanism is activated to enable VLC operation in assisting mode

(Platoon Head BroadCast). The results obtained show a PDR improvement of up to 20% in a high dense scenario.

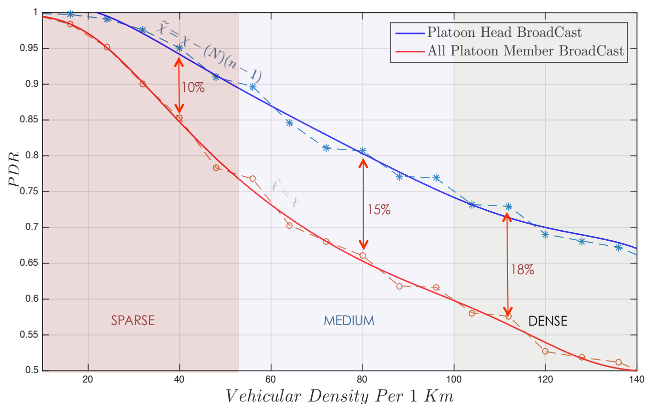

Fig. 11. PDR Simulation results of Scenario I and Scenario II.

The validation of the PVHO mechanism was performed by analyzing the NS3 simulation output of the dynamic time redundancy τ_p, which represents the prediction period due to the calculated θ_p between reaching the prediction angle and the VLC interruption. The sampled results depicted in Figures 12 and 13 are for a 4-vehicle platoon utilizing the PVHO over different speeds (see Fig 10).

The results depicted in Fig 12 is for a platoon with an average speed of 5m/s, where the τ_p is relatively low compared to the 25 m/s scenarios depicted in Fig 13.

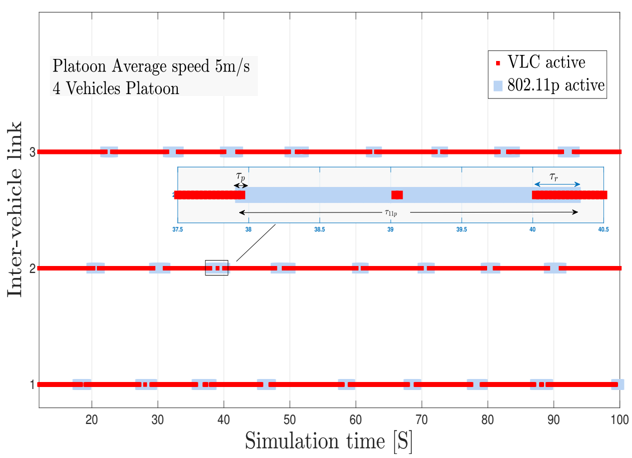

Fig. 12. Four-vehicle platoon connectivity and redundancy results for an average speed of 5 m/s

The simulation results showed that the PVHO could provide a 100% successful prediction rate with redundancy before VLC disconnection, offering a seamless handover over extreme road-curvatures and platoon speeds. The results depicted in Fig 14 summarize the average τ_p obtained for long simulation scenarios and road curvatures.

However, the misalignment causing the VLC interruption occurs on the lane turns depicted in Fig 10. Therefore, and due simulation mobility configuration where the maximum lane speed is 25 m/s with a forced turning speed of 15 m/s,

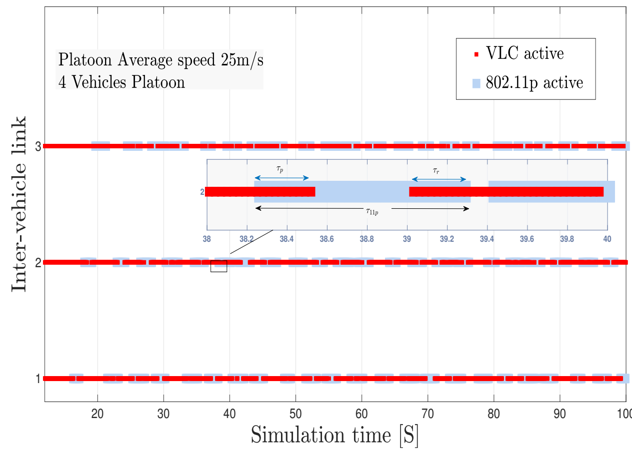

Fig. 13. Four-vehicle platoon connectivity and redundancy results for an average speed of 25 m/s

we can observe the constant τ_p around 300 ms in Fig 14 for any speed exceeding the forced lane turning speed.

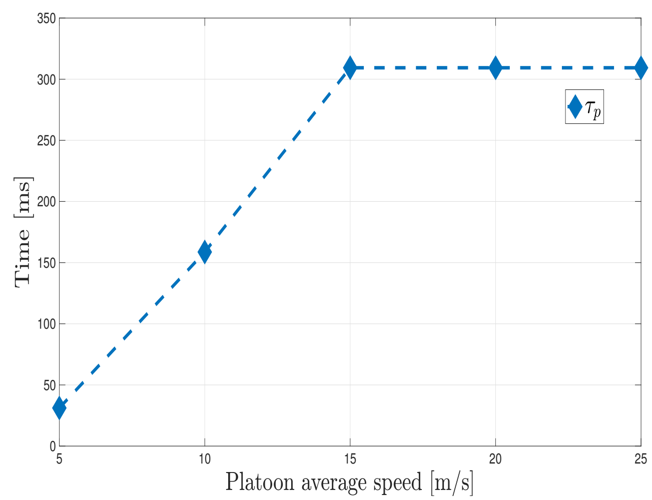

Fig. 14. The prediction redundancy period θ_p for various platoon average speeds

VIII. Conclusion and Future Work

In this paper, we proposed and evaluated the deployment of a prediction-based vertical handover mechanism (PVHO) intended to provide a seamless handover between VLC and the standardized IEEE802.11p communication for convoy-based applications. The algorithm evaluation was carried out in NS3, where we adopted the existing basic VLC-wifi module to handle a vehicular environment and implement the proposed PVHO algorithm.

The overall system performance was evaluated by examining the PDR and the dynamic prediction redundancy period τ_p, where large vehicular scenarios and platoon formations were considered for various road-curvatures and mobilities. The results obtained showed a PDR improvement of up to 20% in a high dense scenario when the PVHO enables the VLC technology to operate in assisting mode. Moreover, the

PVHO reached a 100% successful prediction rate allowing enough redundancy time to perform a seamless handover for extreme road-curvatures and platoon speeds.

However, this is the first step of our proposal validation, where we plan to extend the PVHO algorithm by including radio channel metrics such as the Channel-Busy-Ratio (CBR), which will enable a more extended redundancy period whenever the RF channel congestion level is at a certain safe level. We believe that the developed and validated VLC-NS3 module needs to extend both MAC and PHY layer implementation. Moreover, optical signal reflections, interference, more accurate ambient noise models, and weather conditions are to be further considered.

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